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The integration of dogs into collaborative human-robot teams
- An applied ethological approach -

PhD Thesis

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1. Background, aims and hypothesis

Dogs have been widely used for trained inter-specific cooperative tasks (e.g. search and rescue (SAR) dogs). Also, in modern societies there is an increasing deployment of engineering tools (robots) helping human activities in diverse circumstances, and it might be useful to find ways how such tools could be applied to aid the collaboration of humans and dogs (Britt et al., 2011). In open field SAR missions there is a typical need for dogs and humans to perform their actions to some extent remotely and/or visually separated. Under such circumstances – referred to as heterospheric cooperation (Naderi et al., 2001) –, however, information flow, i.e. communication between the partners is hampered (Bozkurt et al., 2014). It has also been shown that dogs' responsiveness to known commands can be influenced by changes in the humans' communicative signals (Virányi et al., 2004) or visibility (Fukuzawa et al., 2005). By developing technological solutions to receive information about a remote dogs' behaviour (e.g. Brugarolas et al., 2013), as well as identifying further factors that influence dogs' obedience to the handler's commands in heterospheric contexts, it might be possible to improve the extent to which dogs can be integrated into special, trained collaborative tasks. The thesis was born on the grounds of a Synergia project (Swarmix Project). Its overall goal

was to investigate from multiple aspects the practical issue of remote dogs' controllability, In order to gain scientifically grounded support for the elaboration of a procedure that aims to integrate dogs into special open-field scenarios requiring trained collaboration of the remote animal.

Our first two experiments were based on a dog-borne motion sensor device and machine learning algorithm, and we evaluated the success of this system in automatically identifying freely moving dogs' behaviour on open field. We hypothesized that we can identify distinct behaviour categories above chance level, and that the relationship between the used training and validating data in the algorithm, and the complexity of the training data can influence recognition success. We predicted that:

1.1. The system is capable of automatically identifying seven behaviour categories with a success of above 80%.

1.2. Behaviour identification success would be most successful when both training and validating data belong to the same individual.

1.3. Increasing the complexity of the training data (i.e. training the software algorithm with sensor data belonging to several individuals) would improve behaviour recognition success.

The goal of the second experiment was to determine terrain effect on automatic behaviour identification. We hypothesized that both training and validating data influence the success of automatic behaviour identification given that they are collected under characteristically different terrain conditions, and that the application of a 'combined' training data set could be useful for identifying behaviour under diverse terrain conditions. Our predictions were the following:

1.4. Automatic behaviour identification is less successful when motion data are collected under extreme terrain conditions (approx. 30° incline).

1.5. Applying a 'combined' training data set from more types of terrains yields improved behaviour identification success under extreme terrain conditions.

Additionally, in our third experiment we investigated the effect of reward-handler dissociation on dogs' obedience performance to known commands in different heterospheric collaborative contexts, and investigated the influence of proximity and visibility of the handler as well. We hypothesized that recent experience with receiving food reward from a proximate dispenser device would enhance dog's obedience performance in conditions where the distance between the dog and the handler is increased. We predicted that:

2.1. Dogs' obedience performance decreases as the distance between the dog and the handler is increased and/or the handler is not visible

2.2. Dogs respond better to known commands of the handler in distant conditions if they have recent experience with receiving food reward from a proximate dispenser device instead of the handler.

2. Materials and methods

2.1. Automatic identification of dogs' behaviour

The first two experiments were based on a system composed of a multiple sensor data-logger device (with tri-axial accelerometer and tri-axial gyroscope) and a supervised learning algorithm. The animals (N=12-12 Belgian Malinois and Labrador retrievers in the first, and N=12 Labrador retrievers in the second experiment) were equipped with the data logger by means of a harness, and were guided through a predetermined series of standard activities on open field where parallel sensor measurements and video recordings were collected. The first experiment was carried out on plain terrain, while data for the second experiment was collected under terrains with three different steepness; 0° incline, approx. 15° and 30° incline. As part of the data processing, seven

behavioural categories (lay, sit, stand, walk, trot, gallop, canter) were pre-defined and each video recording was tagged accordingly. Evaluation of the measurements was performed by support vector machine (SVM) classification. During the analysis we used different combinations of independent measurements for training and validation.

2.2. Factors affecting the controllability of dogs in heterospheric collaborative contexts

In our third experiment we investigated human-dog interactions under controlled laboratory settings in a cooperative context; we measured family dogs' (N=30 from various breeds) obedience performance to known commands (sit, lay) in different conditions. We manipulated the source of the reward, which was provided for one group of dogs by the handler and for the other group of our subjects by a remote controlled food dispenser device if the dogs responded adequately to the commands. In parallel, there were different conditions where the handler stood either close to the dog, beside a screen, hid behind a screen or was outside of the room while issuing the commands.

3. Results and conclusions

3.1. Automatic identification of dogs' behaviour

3.1.1. We have proved by systematic experimental investigations for the first time that a system of tri-axial accelerometer, tri-axial gyroscope and SVM algorithm is capable of automatically identifying seven behaviour categories (stand, sit, lay, walk, trot, canter, gallop) of freely moving dogs with above 90% success when both training and validating data belonged to the same individual.

3.1.2. We have found a significant drop in automatic behaviour recognition rate (to around 70%) when different individuals were used as training-validation pairs.

3.1.3. Increasing the complexity of the training data by using motion data belonging to several individuals has improved the success of behaviour recognition significantly, which has not been shown elsewhere before.

3.1.4. Our results were the first to show that extreme terrain conditions (approx. 30° incline) significantly decrease the success of automatic behaviour identification when the training data originates from milder terrains (within an incline range of $0^{\circ}<15^{\circ}$).

3.1.5. We have shown that applying a ’combined’ training data set from diverse terrains significantly improves automatic behaviour recognition under extreme terrain conditions.

3.2. Factors affecting the controllability of dogs in heterospheric collaborative contexts

3.2.1. We have shown for the first time in a context where food reward is involved, that short-term reward-handler dissociation attenuates the decrease in dogs’ obedience performance to known commands that occurs at increased distance from the handler and/or due to the handler’s hampered visibility.

Based on our results we can conclude that individual calibration of motion sensor systems used as means of automatic dog behaviour identification can significantly increase behaviour recognition success. Along with this it also seems possible to improve the effectiveness of this method as a more generalized behaviour identifying system in even diverse terrains by extending the complexity of the input training data and thus increasing the robustness of the application. We can also conclude that an acquired reward-handler association might as well play a role in dogs’ tendency for decreased obedience performance at increased distances from their handler.

As part of the 'SWARMIX' international Synergia project, we used our results during the development of an intelligent dog-borne interface that aids communication with the remote dog by transmitting information about the dog's behaviour, and also by allowing for the control of the animal far away from its handler. Additionally, they contributed to the elaboration of a dog training procedure aiming to establish high-level obedience performance even at increased distances from the handler.

Publications

Publications providing the basis of the thesis

Gerencsér, L., Vásárhelyi, G., Nagy, M., Vicsek, T., & Miklósi, Á. (2013). Identification of behaviour in freely moving Dogs (*Canis familiaris*) using Inertial Sensors. *PloS One,* 8(10), e77814.

Miklósi, Á., Gerencsér, L. (2012). Potential application of autonomous and semi-autonomous robots in the study of animal behaviour. *CogInfoCom Proceedings, IEEE, pp. 759-762*

Manuscript under review

Gerencsér, L., Kosztolányi, A., Delanoeije, J., Miklósi, Á. (2015). The effect of reward-handler dissociation on dogs' obedience performance in different conditions. (submitted to *Applied Animal Behaviour Science* in April, 2015, under review).

Related publications

Gerencsér, L. and Vásárhelyi, G. (2015) On dogs and widgets – the automatization of behaviour observation. *Magyar Tudomány* (in Hungarian), 176, 28-35, 2014.

Conference participations

Gerencsér, L., Vásárhelyi, G., Nagy, M., Vicsek, T., Miklósi, Á. (2012). Automated identification of behaviour in freely moving dogs by accelerometer and gyroscope. *3rd Canine Science Forum, Barcelona, Spain,* oral presentation

Gerencsér, L., Vásárhelyi, G., Nagy, M., Vicsek, T., Miklósi, Á. (2013). Identification of behaviour in freely moving dogs using inertial sensors. *3rd CompCog conference, Vienna, Austria,* oral presentation

Gerencsér, L., Vásárhelyi, G., Nagy, M., Vicsek, T., Miklósi, Á. (2013). Automatic Dog Ethogram: Identification of behaviour using inertial sensors. *Conference of the Hungarian Ethology Society, Budapest,* poster

Gerencsér, L., Miklósi, Á. (2014). Integration of dogs into collaborative human-robot teams. *Flynet Workshop, Zürich,* oral presentation

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